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(54) **SYSTEMS AND METHODS FOR CIRCULAR CONVOLUTION**

(71) Applicant: **Huawei Technologies Co., Ltd.**, Shenzhen (CN)

(72) Inventors: **Ming Jia**, Ottawa (CA); **Mohammad Javad Abdoli**, Kanata (CA); **Jianglei Ma**, Ottawa (CA)

(73) Assignee: **HUAWEI TECHNOLOGIES CO., LTD.**, Shenzhen (CN)

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H04L 1/00 (2006.01)
H04L 25/03 (2006.01)

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CPC ***H04L 1/0054*** (2013.01); ***H04L 25/03254*** (2013.01); ***H04L 25/03286*** (2013.01); ***H04L 27/2698*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 1/0054; H04L 27/26; H04L 25/03
See application file for complete search history.

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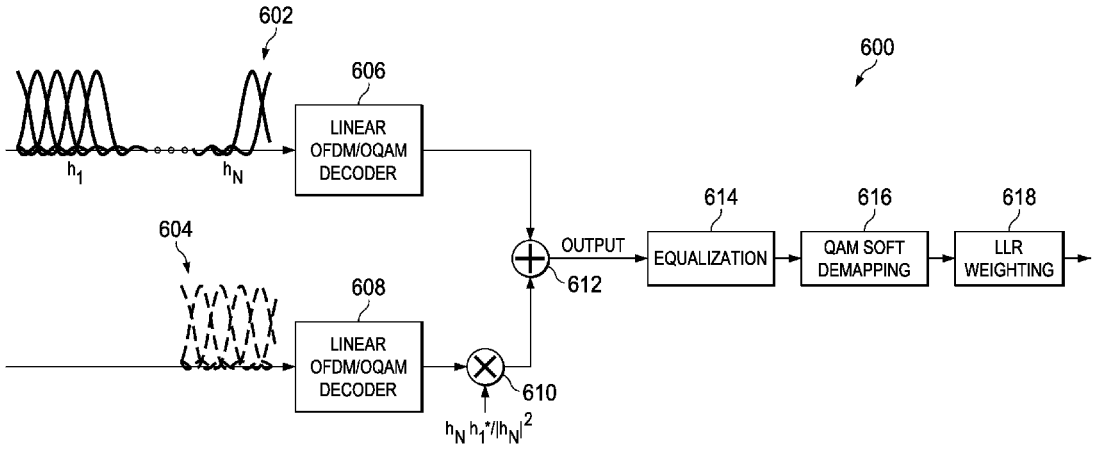
Primary Examiner — Jaison Joseph
(74) *Attorney, Agent, or Firm* — Slater & Matsil, L.L.P.

(57) **ABSTRACT**

System and method embodiments are provided for a receiver for circularly convolved signals. In an embodiment, a universal decoder for a circularly convolved signal includes a first decoder configured to decode the circularly convolved signal; a second decoder configured to decode a plurality of symbol lengths signal from a first portion of the circularly convolved signal, wherein the plurality of symbol lengths signal is time aligned with the circularly convolved signal before passing through the second decoder; and an adder component configured to sum a first decoder output coming from the first decoder and a second decoder output coming from the second decoder to produce a symbol value from which a log likelihood ratio (LLR) output is obtained.

25 Claims, 7 Drawing Sheets



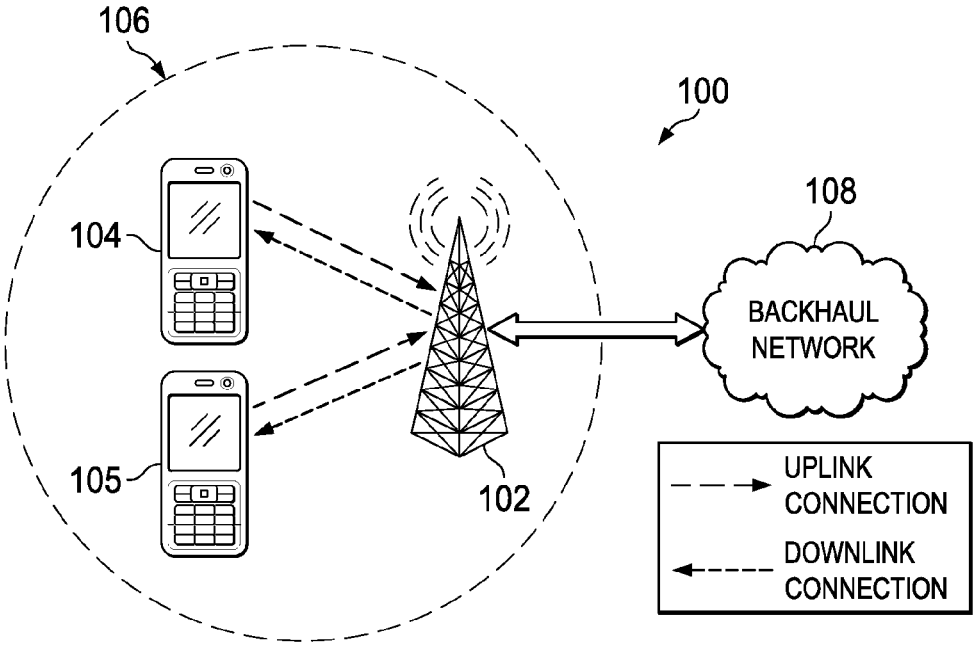

106
100
108
104
BACKHAUL
NETWORK
105
102
UPLINK
CONNECTION
DOWNLINK
CONNECTION

FIG. 1

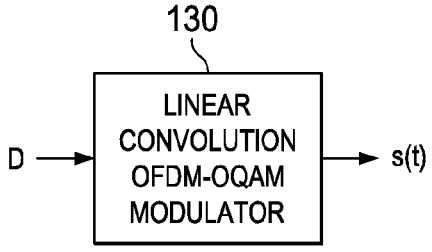

130
D
LINEAR
CONVOLUTION
OFDM-OQAM
MODULATOR
s(t)

FIG. 2

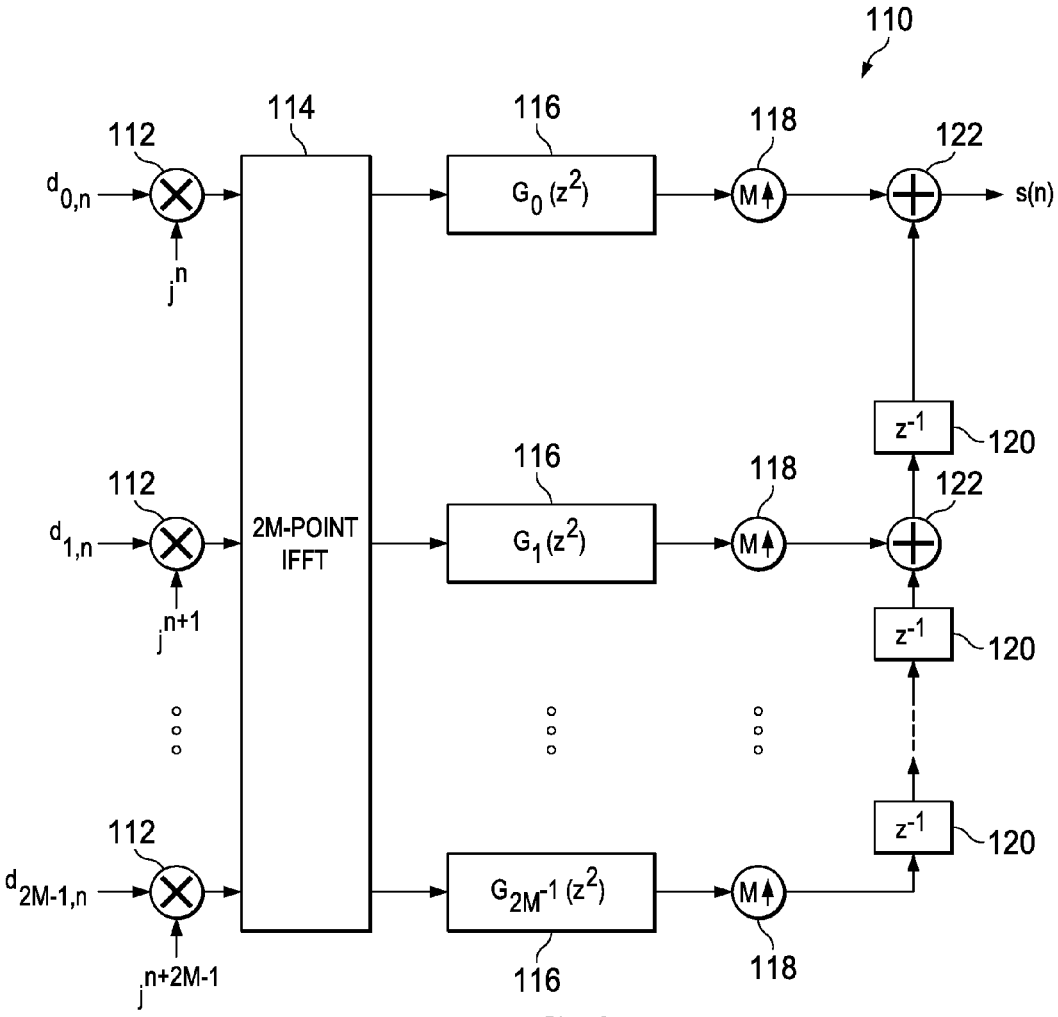

110
112
114
116
118
122
$d_{0,n}$
j^n
$G_0(z^2)$
M
s(n)
z^{-1}
120
$d_{1,n}$
j^{n+1}
2M-POINT IFFT
$G_1(z^2)$
$d_{2M-1,n}$
j^{n+2M-1}
$G_{2M-1}(z^2)$

FIG. 3

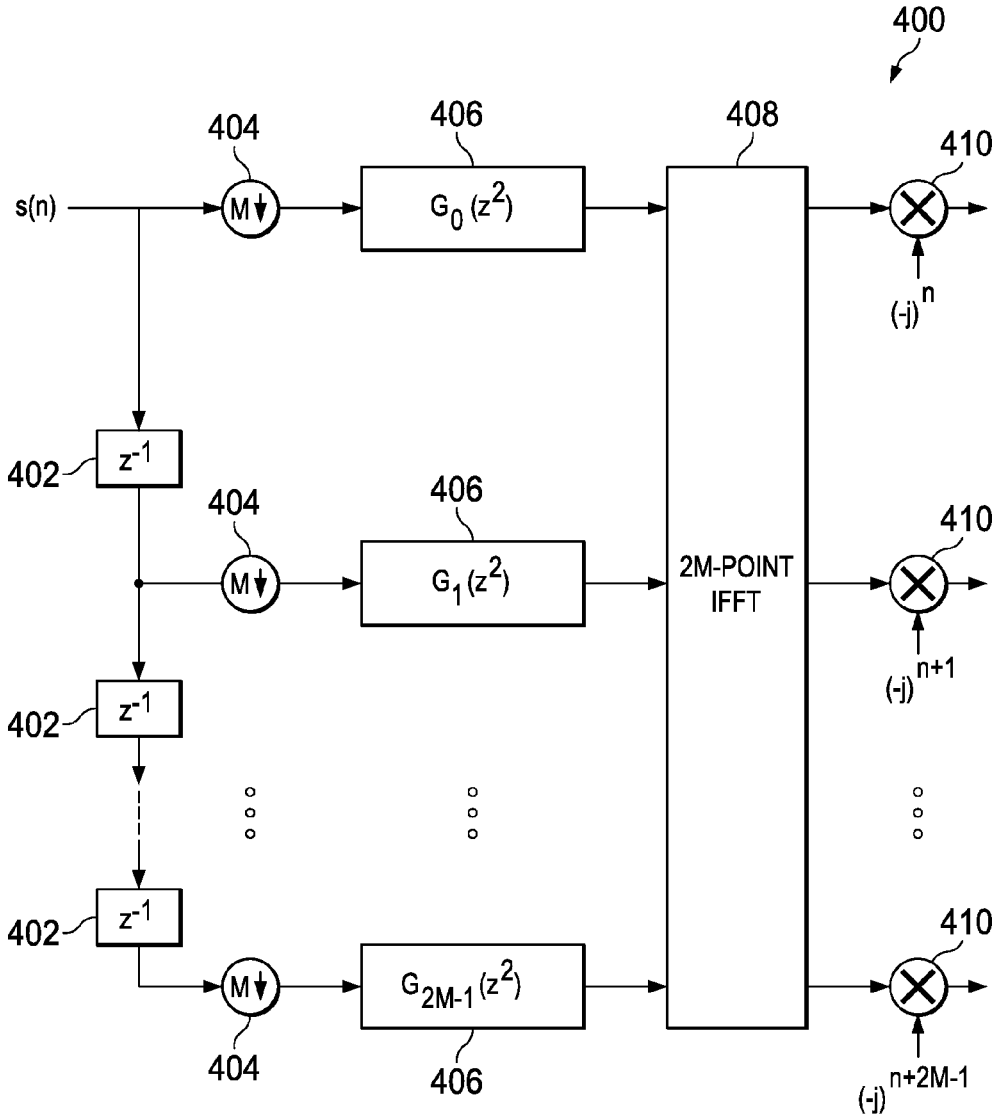

400
404
406
408
410
s(n)
M
$G_0(z^2)$
$(-j)^n$
402
z^{-1}
404
406
410
M
$G_1(z^2)$
2M-POINT IFFT
$(-j)^{n+1}$
402
z^{-1}
402
z^{-1}
410
M
$G_{2M-1}(z^2)$
404
406
$(-j)^{n+2M-1}$

FIG. 4

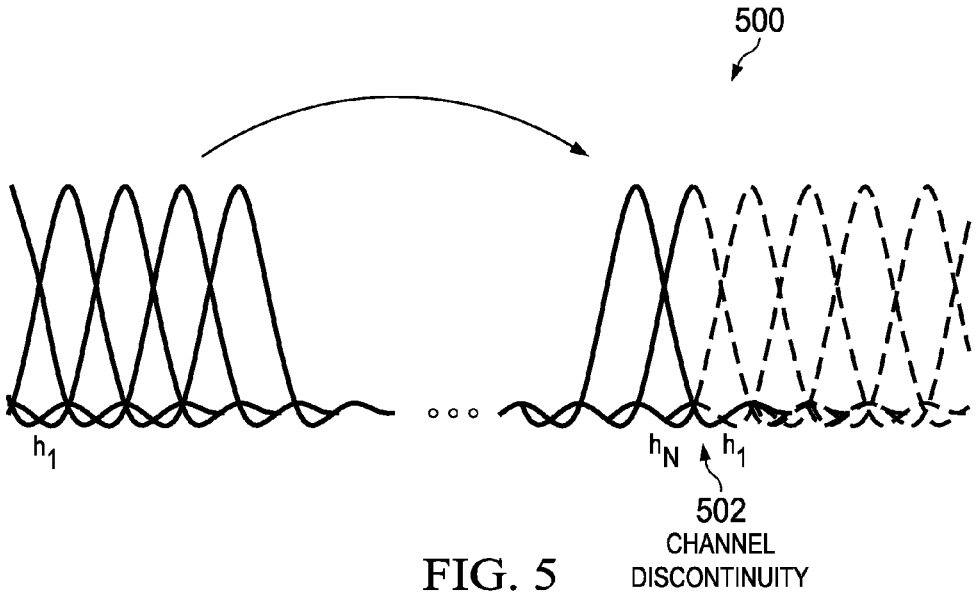

500
h1
hN
h1
502
CHANNEL
DISCONTINUITY

FIG. 5

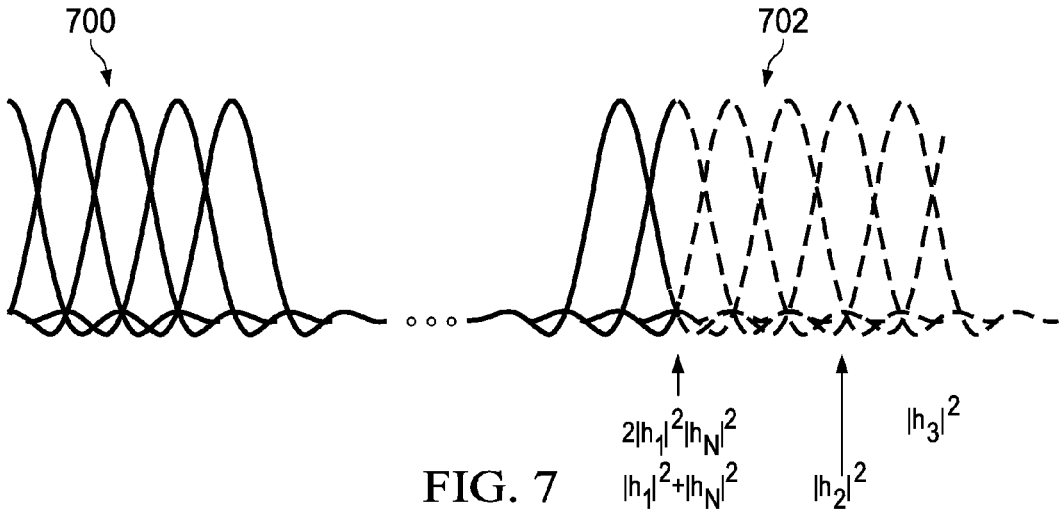

700
702
2|h1|2|hN|2
|h1|2+|hN|2
|h2|2
|h3|2

FIG. 7

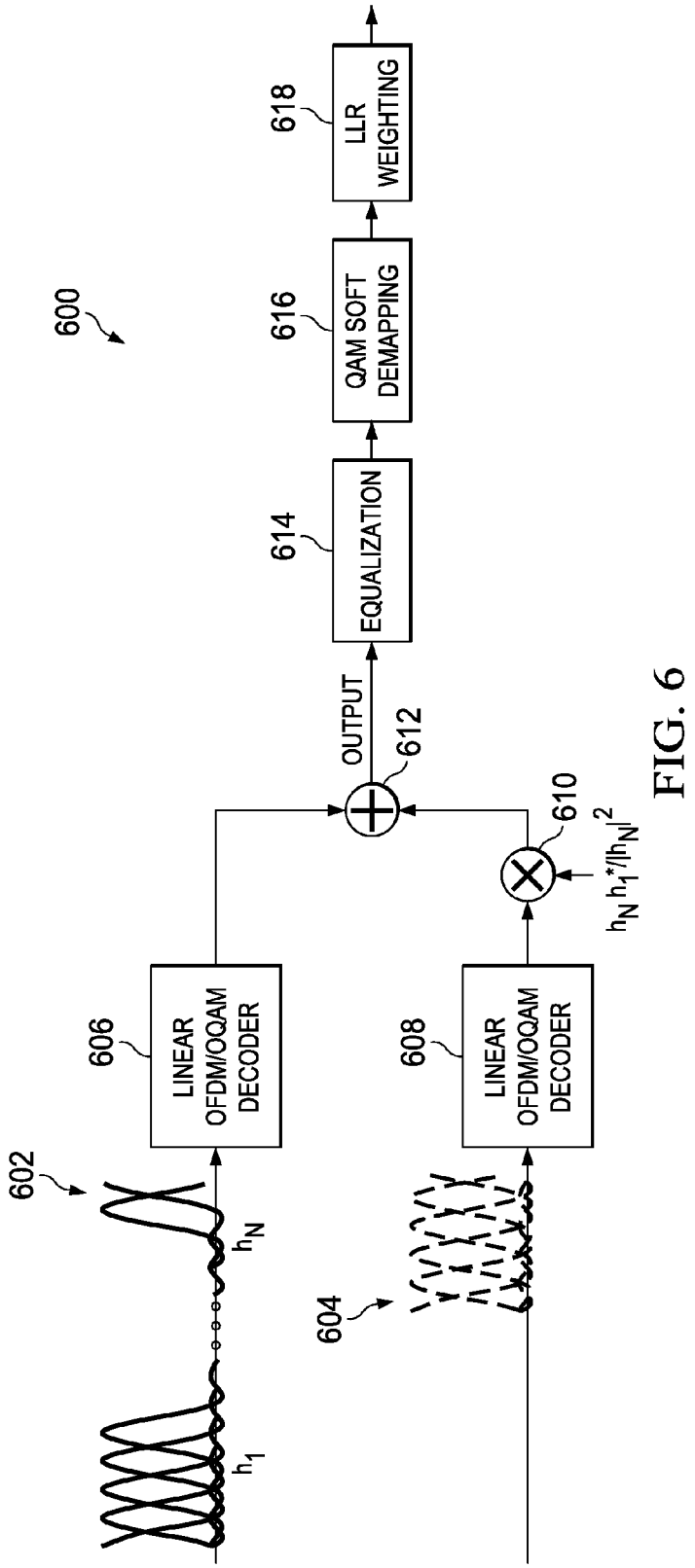

600
602
604
606
LINEAR OFDM/OQAM DECODER
608
LINEAR OFDM/OQAM DECODER
610
$h_N h_1^*/|h_N|^2$
612
OUTPUT
614
EQUALIZATION
616
QAM SOFT DEMAPPING
618
LLR WEIGHTING
h_N
h_1

FIG. 6

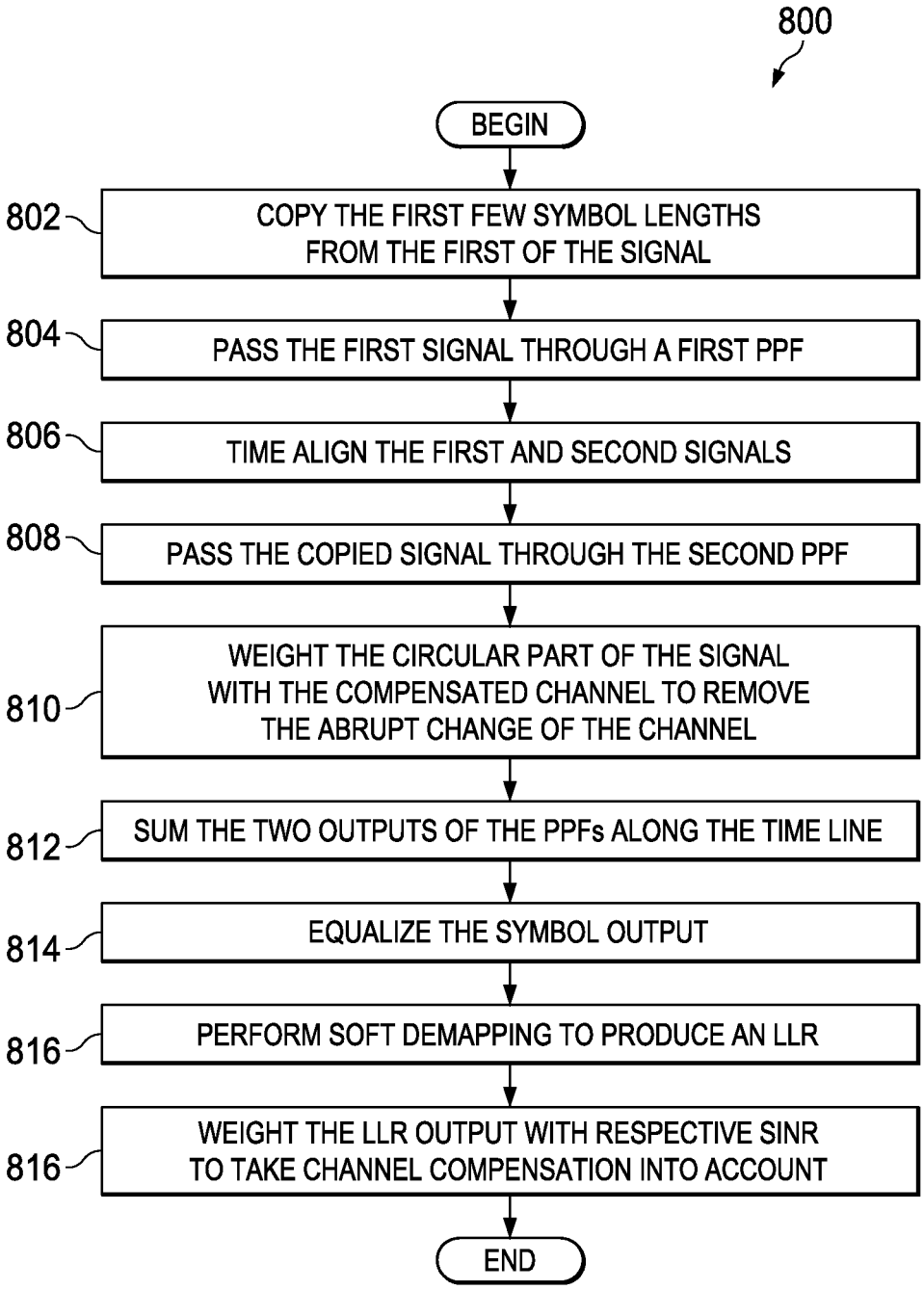

800
BEGIN
802
COPY THE FIRST FEW SYMBOL LENGTHS FROM THE FIRST OF THE SIGNAL
804
PASS THE FIRST SIGNAL THROUGH A FIRST PPF
806
TIME ALIGN THE FIRST AND SECOND SIGNALS
808
PASS THE COPIED SIGNAL THROUGH THE SECOND PPF
810
WEIGHT THE CIRCULAR PART OF THE SIGNAL WITH THE COMPENSATED CHANNEL TO REMOVE THE ABRUPT CHANGE OF THE CHANNEL
812
SUM THE TWO OUTPUTS OF THE PPFs ALONG THE TIME LINE
814
EQUALIZE THE SYMBOL OUTPUT
816
PERFORM SOFT DEMAPPING TO PRODUCE AN LLR
816
WEIGHT THE LLR OUTPUT WITH RESPECTIVE SINR TO TAKE CHANNEL COMPENSATION INTO ACCOUNT
END

FIG. 8

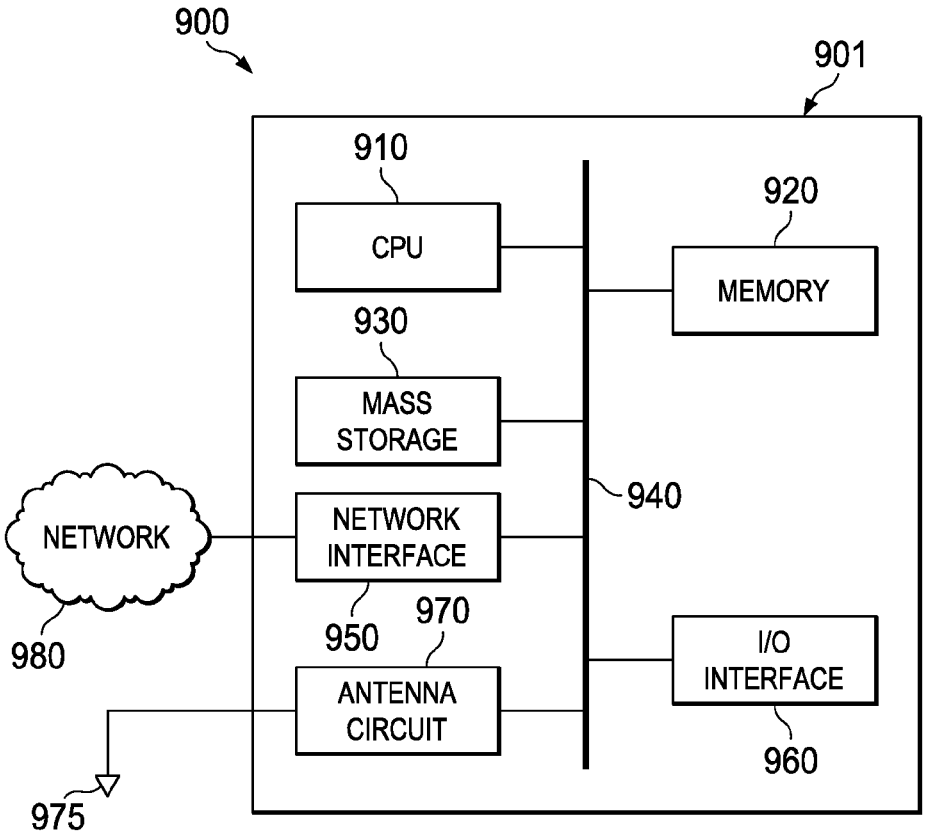

900
901
910
CPU
920
MEMORY
930
MASS STORAGE
940
NETWORK
NETWORK INTERFACE
980
950
970
ANTENNA CIRCUIT
I/O INTERFACE
960
975

FIG. 9

SYSTEMS AND METHODS FOR CIRCULAR CONVOLUTION

TECHNICAL FIELD

The present invention relates to a system and method for wireless communications, and, in particular, to a system and method for compensating for abrupt channel change in circularly convolved signals.

BACKGROUND

In wireless communications, orthogonal frequency division multiplexing (OFDM) may be used as a waveform structure. OFDM has many advantages, including the ease of implementation using fast Fourier transform (FFT) and inverse FFT (IFFT) and robustness against multi-path fading. However, OFDM has drawbacks, such as spectral inefficiency from cyclic-prefix (CP) and frequency guard bands.

OFDM-offset quadrature amplitude modulation (OQAM) is a multi-carrier transmission technique which uses time-frequency localized orthogonal prototype filters, such as root-raised cosine (RRC) and isotropic orthogonal transform algorithm (IOTA) pulse shapes. OFDM-OQAM has a superior power spectral density (PSD) side-lobe decay compared to OFDM. Hence, OFDM-OQAM may reduce the guard band overhead compared to OFDM. For example, in a long term evolution (LTE) system, the overhead may be reduced by 10%, in addition to the gain in spectral efficiency from CP removal. However, OFDM-OQAM incurs an overhead from transmission times of tails at both ends of a transmission burst. OFDM-OQAM has an overhead due to the T/2 time offset between the OQAM symbols, where T is the symbol duration. The total overhead duration is equal to the length of the prototype filter, minus T/2. The length of the prototype filter may be at least 4T to preserve an acceptable inter-symbol interference (ISI) and inter-carrier interference (ICI). For a burst length of 28 OQAM symbols, this is 7/28=25% overhead in time.

Circular convolution has been used in OFDM-OQAM to remove the overhead associated with the pulse tails. It was first proposed in generalized frequency division multiplexing (GFDM) and was later extended to OFDM-OQAM. All the circular convolution based signaling uses the assumption that the channel remains constant in the period for circular convolution. However, in a cellular system, this assumption is often not true. When this happens, the orthogonality between the signal pulses is lost.

SUMMARY

In an embodiment, a universal decoder for a circularly convolved signal includes a first decoder configured to decode the circularly convolved signal; a second decoder configured to decode a plurality of symbol lengths obtained from a first portion of the circularly convolved signal, wherein the plurality of symbol lengths is time aligned with the circularly convolved signal before passing through the second decoder; and an adder component configured to sum a first decoder output coming from the first decoder and a second decoder output coming from the second decoder to produce a symbol value from which a log likelihood ratio (LLR) output is obtained.

In an embodiment, a method for receiving a circularly convolved signal includes passing the circularly convolved signal through a first decoder; passing a plurality of symbol length signal obtained from a portion of the circularly convolved signal through a second decoder, the plurality of symbol length signal is time aligned with the circularly convolved signal before passing through the second decoder; and summing the outputs of the first and second decoder for log likelihood ratio (LLR) de-mapping.

In an embodiment, a network component includes a transmitter and a receiver, wherein the receiver includes a first decoder for decoding a circularly convolved signal; a second decoder for decoding a plurality of symbol lengths signal obtained from a first portion of the circularly convolved signal, wherein the plurality of symbol lengths signal is time aligned with the circularly convolved signal before passing through the second decoder; and an adder component for summing a first decoder output coming from the first decoder and a second decoder output coming from the second decoder to produce a symbol value from which a log likelihood ratio (LLR) output is obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

FIG. **1** illustrates network for communicating data;

FIG. **2** illustrates a flowchart for a method of linear convolution modulation;

FIG. **3** illustrates a flowchart for a method of linear convolution demodulation;

FIG. **4** illustrates an embodiment OFDM-OQAM modulator poly-phase structure which may be used to implement OFDM-OQAM modulation;

FIG. **5** is a graph illustrating channel discontinuity;

FIG. **6** illustrates an embodiment system for a circularly convolved decoder;

FIG. **7** illustrates a graph of a transmission burst with a discontinuity and an LLR weighting function utilized for the reconstructed symbol;

FIG. **8** is a flowchart of an embodiment method for obtaining a symbol from a circularly convoluted signal at a discontinuity; and

FIG. **9** is a block diagram of a processing system that may be used for implementing the devices and methods disclosed herein.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of the presently preferred embodiments are discussed in detail below. It should be appreciated, however, that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use the invention, and do not limit the scope of the invention.

An OFDM-OQAM receiver may feed the received signal into a poly-phase filter (PPF) decoder. This works well for a weighted circularly convolved (WCC) signal when the channel is static in time. However, when the channel is not static in time, significant self-interference can occur at the edge of the reconstructed WCC signal.

Disclosed herein are various embodiments about systems and methods to compensate for channel discontinuity resulting from user equipment (UE) mobility in a wireless network for circularly convolved signals. In an embodiment, the receiver is separated into two parts: one for the received signal and the other for the circularly attached signal. The disclosed

systems and methods compensate for the channel discontinuity at the edge of the circular operation for the circularly attached signal. The outputs of the two signals are aligned in time and then added together. After passing through the channel equalizer component and QAM soft demapper, the log likelihood ratio (LLR) output will be weighted appropriately with channel discontinuity taken into account. The compensation is performed at the joint point where the channel discontinuity occurs. Thus, it does not matter how fast the UE moves or how long it takes for the channel to change.

Disclosed herein is an embodiment of a method for splitting a WCC signal into two separate sequences along the edge. The two signals pass through two separate PPFs. The circular part of the signal is weighted with the compensated channel to remove the abrupt change of the channel and the two outputs (e.g., from the original signal passing through the first PPF and the compensated signal passing through the second PPF) are summed along the time line. In an embodiment, the LLR output is weighted with channel compensation being taken into account. The cost incurred in the disclosed method is two separate PPFs, but only for the overlapping part (i.e., about the length of four OFDM-OQAM symbol lengths). For the remainder of the signal burst, only one PPF is needed. Thus, the disclosed systems and methods compensate for the abrupt channel change for the short output sequence. The output from the two PPFs are combined for LLR de-mapping.

An advantage of the disclosed systems and methods is that a universal decoder can be used regardless of the terminal mobility. Another advantage of some embodiments of the disclosed systems and methods is that it is not necessary to worry about the mobility of the UE and the transmitter does not have to tell the receiver what to do through signaling, thereby reducing overhead through less signaling. In an embodiment, if the channel does not change, then no compensation is performed. In embodiments, the circularly convolved OFDM-OQAM is immune to user mobility.

Although described herein primarily with reference to OFDM-OQAM, it should be recognized that the disclosed systems and methods are not limited to OFDM-OQAM, but can be applied to any circularly convolved signal, such as, for example, Generalized Frequency Division Multiplexing (GFDM).

An OFDM-OQAM can be expressed as a linear convolution of the input (up-sampled) OQAM sequence with a bank of frequency-modulated versions of the prototype filter. In an embodiment, the operation of a linear convolution is imitated in circular convolution, but with a compensated channel. In an embodiment, the same modulator is used at the transmitter and the same demodulator is used at the receiver regardless of UE mobility.

In an embodiment, a universal decoder independent of terminal mobility for a circularly convolved signal includes a first decoder for decoding the circularly convolved signal; a second decoder for decoding a copied first plurality of symbol lengths from the circularly convolved signal, wherein the copied first plurality of symbol lengths is time aligned with the circularly convolved signal before passing through the second decoder; and an adder component for summing a first output of the first decoder and a second output of the second decoder to produce a sequence of unequalized signal output. In an embodiment, the decoder includes a multiplier component for weighting a circular part of the signal with weighting factor determined according to a compensated channel to remove an abrupt change of the channel. In an embodiment, the weighting factor is determined according to $h_N h^*_1/|h_1|^2$, where h_1 is a channel at the beginning of the circularly convolved signal and h_N is a channel at the end of the circularly convolved signal. In an embodiment, the decoders are linear OFDM-OQAM decoders. In an embodiment, the decoders are poly-phase filters (PPFs). In an embodiment, the adder component is configured to weight the LLR output is normalized or equalized with a weighting factor with channel compensation taken into account. In an embodiment, the weighting factor is given by

$$\frac{2|h_1|^2|h_N|^2}{|h_1|^2+|h_N|^2}$$

where h_1 is a channel at the beginning of the circularly convolved signal and h_N is a channel at the end of the circularly convolved signal.

In an embodiment, a method for receiving a circularly convolved signal includes copying a plurality of first signal lengths from the circularly convolved signal; passing the circularly convolved signal through a first decoder; passing the copied signal through a second decoder; and summing the outputs of the first and second decoder for channel equalization and log likelihood ratio (LLR) de-mapping. In an embodiment, the method further includes time aligning the circularly convolved signal and the copied signal and weighting a circular part of the signal with a weighting factor according to a compensated channel to remove an abrupt change of the channel. In an embodiment, the method also includes weighting the LLR de-mapping output with a weighting factor according to channel compensation. In an embodiment, the plurality of first signal lengths is about four symbol lengths. In an embodiment, the plurality of first signal lengths is a length of a prototype filter minus T/2, where T is an offset quadrature amplitude modulation (OQAM) symbol duration.

FIG. **1** illustrates network **100** for communicating data. Network **100** comprises communications controller **102** having a coverage area **106**, a plurality of user equipment (UEs), including UE **104** and UE **105**, and backhaul network **108**. Two UEs are depicted, but many more may be present. Communications controller **102** may be any component capable of providing wireless access by, inter alia, establishing uplink (dashed line) and/or downlink (dotted line) connections with UE **104** and UE **105**, such as a base station, an enhanced base station (eNB), a picocell, a femtocell, and other wirelessly enabled devices. UE **104** and UE **105** may be any component capable of establishing a wireless connection with communications controller **102**, such as cell phones, smart phones, tablets, sensors, etc. Backhaul network **108** may be any component or collection of components that allow data to be exchanged between communications controller **102** and a remote end (not shown). In some embodiments, the network **100** may comprise various other wireless devices, such as relays, femtocells, etc.

FIG. **2** illustrates a flowchart for a method of linear convolution OFDM-OQAM modulation. An input data burst D is linearly convolved by linear convolution OFDM-OQAM modulator **130** to produce output signal s(t). An example data burst is given by:

$$D=\begin{bmatrix} d_{0,1} & d_{0,2} & \cdots & d_{0,N} \\ d_{1,1} & d_{1,2} & \cdots & d_{1,N} \\ \vdots & \vdots & \ddots & \vdots \\ d_{2M-1,1} & d_{2M-1,2} & \cdots & d_{2M-1,N} \end{bmatrix},$$

where the columns correspond to frequency and the rows correspond to time. In data burst D, there are 2M subcarriers, and N symbols in time.

In linear convolution OFDM-OQAM modulation, a sequence of OQAM symbols is modulated over a set of real-orthogonal pulse shapes. The pulse shapes are obtained by shifting a symmetrical real-valued prototype filter p(t) in time and frequency. For a continuous time OFDM-OQAM signal, the modulator output may be written as:

$$s(t)=\sum_{n=-\infty}^{+\infty}\sum_{k=0}^{M-1} d_{2k,2n}p(t-nT)e^{\frac{j2\pi(2k)t}{T}}+j\cdot d_{2k,2n+1}p\left(t-\frac{T}{2}-nT\right)e^{\frac{j2\pi(2k)t}{T}}+$$

$$j\cdot d_{2k+1,2n}p(t-nT)e^{\frac{j2\pi(2k+1)t}{T}}+d_{2k+1,2n+1}p\left(t-\frac{T}{2}-nT\right)e^{\frac{j2\pi(2k+1)t}{T}}.$$

The real-valued constellation points are given by $d_{k,n}$. The real-valued constellation points may be, for example, pulse-amplitude modulating (PAM) symbols or real or imaginary parts of quadrature amplitude modulation (QAM) symbols. The number of subcarriers is 2M, the subcarrier spacing is 1/T, and the time spacing between two consecutive OQAM symbols is T/2. The real-orthogonality implies that:

$$R\left\{\int_{-\infty}^{+\infty} p\left(t-\frac{nT}{2}\right)p\left(t-\frac{n'T}{2}\right)\times e^{\frac{j2\pi(n'-m)t}{T}}e^{j2\pi(\varphi_{m',n'}-\varphi_{m,n})}dt\right\}=$$

$$\delta_{m,m'}\delta_{n,n'},$$

where:

$$\varphi_{m,n}\triangleq\frac{\pi}{2}(m+n).$$

The discrete-time formulation of OFDM-OQAM transmission is realized by sampling the continuous-time signal with a sampling period of:

$$T_S=T/2M.$$

That is:

$$s(m)=\sum_{n=-\infty}^{+\infty}\sum_{k=0}^{2M-1} d_{k,n}p(m-nM)e^{\frac{j2\pi km}{2M}}e^{j\varphi_{k,n}}.$$

FIG. **3** illustrates OFDM-OQAM modulator poly-phase structure **110** which may be used to implement OFDM-OQAM modulation. The input data points are $d_{k,n}$, where k represents the subcarrier and n represents the symbol in time. The inputs are multiplied by J^{n+k} in multiplier blocks **112**. Then, IFFT block **114**, a 2M-point IFFT, performs IFFT. After IFFT block **114**, linear convolution filters **116** perform linear convolution using transfer functions $G_k(z^2)$. Expansion blocks **118** expand the outputs of linear convolution filters **116** by a factor M. The outputs of expansion blocks **118** are then time shifted by time shift blocks **120**, and added by adders **122** to produce output signals(n).

FIG. **4** illustrates an OFDM-OQAM demodulator poly-phase structure **400** which may be used to implement OFDM-OQAM demodulation. The input data signal is s(n) where n represents the symbol in time. The input data signal s(n) is split and time shifted by time shift blocks **402**. The output of the time shift blocks **402** is condensed by condensing blocks **404** by a factor M. The outputs of the condensing blocks **404** are passed through linear convolution filters **406** that perform linear convolution using transfer functions $G_k(z^2)$. The IFFT block **408**, a 2M-point IFFT, performs IFFT on the output of the convolution filters **406**. The outputs of the IFFT block **408** is multiplied by $(-j)^{n+k}$ in multiplier block **410** to produce the output non-equalized data points, where k represents the subcarrier and n represents the symbol in time.

FIG. **5** is a graph **500** illustrating channel discontinuity. Graph **500** shows the copy-and-append operation that is performed in a regular receiver for circular convolution OFDM-OQAM. In this operation, the first part of the signal is copied and appended to the end of the signal (and t_he resulting signal is passed though a single linear OFDM-OQAM decoder). A channel discontinuity occurs at point **502** between h_N and h_1. A channel discontinuity causes a loss of orthogonality. Thus, if they are no longer orthogonal, the symbol across the channel h_1 to h_N is useless. In order to mitigate this discontinuity, in an embodiment, the first part of the signal is copied and shifted in time and processed through a second OFDM-OQAM decoder and the output of the decoder is weighted appropriately as described below with reference to FIG. **6**.

FIG. **6** illustrates an embodiment system **600** for a circularly convolved decoder. System **600** includes two linear OFDM-OQAM decoders **606**, **608**. The first linear OFDM-OQAM decoder **606** normally operates similar to demodulator **150** in FIG. **3**. System **600** also includes a multiplier **610**, an adder **612**, an equalization component **614**, a QAM soft demapping component **616**, and an LLR weighting component **618**. The beginning portion of the transmission burst is copied to the input of the second decoder **608** and time aligned with the last portion of the transmission burst. The multiplier weights the first portion of the transmission burst. In an embodiment, the duration of the first portion of time is equal to the duration of a prototype filter minus T/2 (i.e., the overhead of the linear convolution OFDM-OQAM which is removed in circular convolution OFDM-OQAM), where T is OQAM symbol duration time. In an embodiment, the weighting removes the abrupt channel change. However, in an embodiment, due to this weighting, the LLR output is properly weighted by taking this first weighting into account. The multiplier **610** removes the effect of h_1 and masks the pulse as it goes through channel h_N. In an embodiment, the multiplier **610** multiplies the output of decoder **608** by a weighting function given by the value of

$$\frac{h_n h_1^*}{|h_1|^2},$$

where h_1 is a channel value at the beginning of the circularly convolved signal, h_N is a channel value at the end of the circularly convolved signal, h^*_1 is the complex conjugate of h_1, and $|h_1|$ is the amplitude of h_1. The channel value, h_i, is the estimated channel value at time i and may be a complex value. The output of the second decoder **608** and multiplier **610** is added to the output of the first decoder **606** and the output from the adder **612** is the de-mapped symbol. The de-mapped symbol is passed through equalization component **614** to equalize the de-mapped symbol to remove the channel effect for QAM. The output from the equalization component **614** is passed through the QAM soft demapping component **616**, which generates an unweighted LLR. The output (unweighted LLR) from the QAM soft demapping component **616** is passed through the LLR weighting component **518** which weights each unweighted LLR by a respective signal-to-interference-plus-noise ratio (SINR) which takes the channel weighting performed earlier at the demodulation stage into account.

In an embodiment, the multiplier **610** is placed before the decoder **608** instead of after as shown in FIG. **6**.

FIG. **7** illustrates a graph **700** of a transmission burst with a discontinuity and an LLR weighting function utilized for the reconstructed symbol. Graph **700** shows a discontinuity at point **702**. A weighting function is used to aid in symbol reconstruction. In an embodiment, the weighting function is a LLR. In an embodiment, the weighting function is given by

$$\frac{2|h_1|^2|h_N|^2}{|h_1|^2 + |h_N|^2}$$

where h_1 is a channel at the beginning of the circularly convolved signal, h_N is a channel at the end of the circularly convolved signal, $|h_1|$ is the amplitude of h_1, and $|h_N|$ is the amplitude of h_N. In an embodiment, it may be necessary to pay special attention to the LLR weighting for the reconstructed symbol at the end of the transmitted signal burst because the channel compensation step may cause "noise enhancement." In an embodiment, the LLR output of each demapped QAM symbol is weighted by the SNR of that particular symbol to reduce the effect of "noise enhancement."

FIG. **8** is a flowchart of an embodiment method **800** for obtaining a symbol from a circularly convoluted signal at a discontinuity. The method **800** begins at block **802** where the first few symbol lengths of the first signal are copied. At block **804**, the first signal is passed through a first PPF. AT block **806**, the first and second signals are time aligned and at block **808**, the copied signal (that includes just the first few symbol lengths from the beginning or first of the signal) is passed through the second PPF. At block **810**, the circular part of the signal is weighted with the compensated channel to remove the abrupt change of the channel. At block **812**, the two outputs from the two PPFs are summed along the time line to produce a demodulated symbol output. At block **814**, the demodulated symbol output is equalized. At block **816**, the equalized symbol output is soft demapped to produce an unweighted LLR. At block **818**, the unweighted LLR output is weighted with channel compensation taken into account, after which, the method **800** ends.

FIG. **9** is a block diagram of a processing system **900** that may be used for implementing the devices and methods disclosed herein. Specific devices may utilize all of the components shown, or only a subset of the components and levels of integration may vary from device to device. Furthermore, a device may contain multiple instances of a component, such as multiple processing units, processors, memories, transmitters, receivers, etc. The processing system **900** may comprise a processing unit **901** equipped with one or more input/output devices, such as a speaker, microphone, mouse, touchscreen, keypad, keyboard, printer, display, and the like. The processing unit **901** may include a central processing unit (CPU) **910**, memory **920**, a mass storage device **930**, a network interface **950**, an I/O interface **960**, and an antenna circuit **970** connected to a bus **940**. The processing unit **901** also includes an antenna element **975** connected to the antenna circuit.

The bus **940** may be one or more of any type of several bus architectures including a memory bus or memory controller, a peripheral bus, video bus, or the like. The CPU **910** may comprise any type of electronic data processor. The memory **920** may comprise any type of system memory such as static random access memory (SRAM), dynamic random access memory (DRAM), synchronous DRAM (SDRAM), read-only memory (ROM), a combination thereof, or the like. In an embodiment, the memory **920** may include ROM for use at boot-up, and DRAM for program and data storage for use while executing programs.

The mass storage device **930** may comprise any type of storage device configured to store data, programs, and other information and to make the data, programs, and other information accessible via the bus **940**. The mass storage device **930** may comprise, for example, one or more of a solid state drive, hard disk drive, a magnetic disk drive, an optical disk drive, or the like.

The I/O interface **960** may provide interfaces to couple external input and output devices to the processing unit **901**. The I/O interface **960** may include a video adapter. Examples of input and output devices may include a display coupled to the video adapter and a mouse/keyboard/printer coupled to the I/O interface. Other devices may be coupled to the processing unit **901** and additional or fewer interface cards may be utilized. For example, a serial interface such as Universal Serial Bus (USB) (not shown) may be used to provide an interface for a printer.

The antenna circuit **970** and antenna element **975** may allow the processing unit **901** to communicate with remote units via a network. In an embodiment, the antenna circuit **970** and antenna element **975** provide access to a wireless wide area network (WAN) and/or to a cellular network, such as Long Term Evolution (LTE), Code Division Multiple Access (CDMA), Wideband CDMA (WCDMA), and Global System for Mobile Communications (GSM) networks. In some embodiments, the antenna circuit **970** and antenna element **975** may also provide Bluetooth and/or WiFi connection to other devices.

The processing unit **901** may also include one or more network interfaces **950**, which may comprise wired links, such as an Ethernet cable or the like, and/or wireless links to access nodes or different networks. The network interface **901** allows the processing unit **901** to communicate with remote units via the networks **980**. For example, the network interface **950** may provide wireless communication via one or more transmitters/transmit antennas and one or more receivers/receive antennas. In an embodiment, the processing unit **901** is coupled to a local-area network or a wide-area network for data processing and communications with remote devices, such as other processing units, the Internet, remote storage facilities, or the like.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is therefore intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

1. A universal decoder for a circularly convolved signal, comprising:

a first decoder configured to decode the circularly convolved signal;

a second decoder configured to decode a plurality of symbol lengths signal obtained from a first portion of the circularly convolved signal, wherein the plurality of symbol lengths signal is time aligned with the circularly convolved signal before passing through the second decoder; and

an adder component configured to sum a first decoder output coming from the first decoder and a second

decoder output coming from the second decoder to produce a symbol value from which a log likelihood ratio (LLR) output is obtained.

2. The decoder of claim **1**, further comprising a multiplier component configured to weight a circular part of the signal with a weighting factor in order to remove an abrupt change of a channel, wherein the weighting is determined according to a compensated channel.

3. The decoder of claim **2**, wherein the weighting factor is determined according to

$$\frac{h_n h_1^*}{|h_1|^2},$$

where h_1 is a channel value at the beginning of the circularly convolved signal, h_N is a channel value at the end of the circularly convolved signal, h^*_1 is the complex conjugate of h_1, and $|h_1|$ is the amplitude of h_1.

4. The decoder of claim **1**, wherein the decoders comprise linear orthogonal frequency division multiplexing (OFDM)-offset quadrature amplitude modulation (OQAM) decoders.

5. The decoder of claim **1**, wherein the decoders comprise poly-phase filters.

6. The decoder of claim **1**, wherein the plurality of symbol lengths comprises a length of prototype filter minus T/2, where T is an offset quadrature amplitude modulation (OQAM) symbol duration.

7. The decoder of claim **1**, further comprising an LLR weighting component configured to weight the LLR output with a weighting factor with channel compensation taken into account.

8. The decoder of claim **7**, wherein the weighting factor is given by

$$\frac{2|h_1|^2|h_N|^2}{|h_1|^2+|h_N|^2}$$

where h_1 is a channel at the beginning of the circularly convolved signal, h_N is a channel at the end of the circularly convolved signal, $|h_1|$ is the amplitude of h_1, and $|h_N|$ is the amplitude of h_N.

9. The decoder of claim **1**, further comprising:

an equalizer component to remove a channel effect from the symbol; and

a quadrature amplitude modulation (QAM) soft demapping component to generate an unweighted LLR.

10. A method for receiving a circularly convolved signal, the method comprising:

passing the circularly convolved signal through a first decoder;

passing a plurality of symbol length signal obtained from a first portion of the circularly convolved signal through a second decoder, the plurality of symbol length signal is time aligned with the circularly convolved signal before passing through the second decoder; and

summing the outputs of the first and second decoder for a log likelihood ratio (LLR) de-mapping output.

11. The method of claim **10**, further comprising weighting a circular part of the signal with a weighting factor according to a compensated channel to remove an abrupt change of the channel.

12. The method of claim **11**, wherein the weighting factor is determined according to

$$\frac{h_n h_1^*}{|h_1|^2},$$

where h_1 is a channel value at the beginning of the circularly convolved signal, h_N is a channel value at the end of the circularly convolved signal, h^*_1 is the complex conjugate of h_1, and $|h_1|$ is the amplitude of h_1.

13. The method of claim **10**, further comprising weighting the LLR de-mapping output with a weighting factor according to channel compensation.

14. The method of claim **13**, wherein the weighting factor is given by

$$\frac{2|h_1|^2|h_N|^2}{|h_1|^2+|h_N|^2}$$

where h_1 is a channel at the beginning of the circularly convolved signal, h_N is a channel at the end of the circularly convolved signal, $|h_1|$ is the amplitude of h_1, and $|h_N|$ is the amplitude of h_N.

15. The method of claim **10**, wherein the decoders comprise linear orthogonal frequency division multiplexing (OFDM)/offset quadrature amplitude modulation (OQAM) decoders.

16. The method of claim **10**, wherein a plurality of first signal lengths comprises a length of prototype filter minus T/2, where T is OQAM symbol duration.

17. A network component, comprising:

a transmitter; and

a receiver, wherein the receiver comprises:

a first decoder for decoding a circularly convolved signal;

a second decoder for decoding a plurality of symbol lengths signal obtained from a first portion of the circularly convolved signal, wherein the plurality of symbol lengths signal is time aligned with the circularly convolved signal before passing through the second decoder; and

an adder component for summing a first decoder output coming from the first decoder and a second decoder output coming from the second decoder to produce a symbol value from which a log likelihood ratio (LLR) output is obtained.

18. The network component of claim **17**, further comprising a multiplier component for weighting a circular part of the signal with weighting factor determined according to a compensated channel to remove an abrupt change of the channel.

19. The network component of claim **18**, wherein the weighting factor is determined according to

$$\frac{h_n h_1^*}{|h_1|^2},$$

where h_1 is a channel value at the beginning of the circularly convolved signal, h_N is a channel value at the end of the circularly convolved signal, h^*_1 is the complex conjugate of h_1, and $|h_1|$ is the amplitude of h_1.

20. The network component of claim **17**, wherein the decoders comprise linear orthogonal frequency division multiplexing (OFDM)/offset quadrature amplitude modulation (OQAM) decoders.

21. The network component of claim **17**, wherein the decoders comprise poly-phase filters.

22. The network component of claim **17**, wherein the copied first plurality of symbol lengths comprises a length of prototype filter minus T/2, where T is OQAM symbol duration.

23. The network component of claim **17**, wherein the adder component is further configured to weight the LLR output with a weighting factor with channel compensation taken into account.

24. The network component of claim **23**, wherein the weighting factor is given by

$$\frac{2|h_1|^2|h_N|^2}{|h_1|^2+|h_N|^2}$$

where h_1 is a channel at the beginning of the circularly convolved signal, h_N is a channel at the end of the circularly convolved signal, $|h_1|$ is the amplitude of h_1, and $|h_N|$ is the amplitude of h_N.

25. The network component of claim **17**, wherein the receiver further comprises:

an equalizer component to remove a channel effect from the symbol; and

a quadrature amplitude modulation (QAM) soft demapping component to generate an unweighted LLR.

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